Chapter 5
SEISMIC HAZARDS

5.1 INTRODUCTION

This chapter reviews the assessment of seismic hazards, their different aspects and principle causes, and the methods and data required. Mainly standard methods and techniques are described that have been applied in many countries around the world and have produced reliable results.

The primary hazard results from the direct effects of earthquake motion. Earthquake triggered sea waves, avalanches, rockfalls and landslides are considered to be secondary hazards, which may be important in certain areas. These hazards, their resulting risks and how to deal with them, are not covered in this chapter A comprehensive description can be found in Horlick-Jones *et al.* (1995).

Earthquake hazard evaluation is the initial step in the general strategy of risk assessment and disaster mitigation measures in seismically active areas. Seismic risk is thereby assumed to be composed of: (1) seismic hazard; (2) vulnerability; and (3) exposure of persons and goods to primary (and secondary) hazards. The complete disaster management and risk reduction plan comprises the following actions and professionals (SEISMED, 1990)

Seismic hazard assessment. Professionals involved are essentially seismologists, geologists and geotechnical engineers. Their activities are devoted to the production of various types of technical maps with site-specific hazard figures. Earthquake hazard is usually expressed in probabilities of occurrence of a certain natural earthquake effect (e.g., level of strong ground shaking) in a given time frame.

Vulnerability analysis. Professionals involved are mainly civil and geotechnical engineers and architects investigating the interaction between soil and structures under seismic load and the susceptibility of structures to damage. Typical vulnerability figures are presented as the percentage of a building type showing damage of a certain degree due to a selected seismic ground motion level.

Exposure evaluation. The socio-geographical and economical aspects of an environment prone to earthquakes are evaluated by planners, engineers, economists and administrators.

The results of these investigations will ultimately be the guide to adequate actions (Hays, 1990), such as.

Planning: The evaluation of the expected losses due to strong earthquakes should lead to a revision in urban and regional planning, as well as to procedures for limiting damage to buildings (e.g. building codes and regulations).

Administration: The earthquake-resistant design specifications (e.g., zoning maps) that have been studied and produced by the scientific and engineering communities become instruments for disaster mitigation.

Disaster preparedness: The logistical and administrative authorities prepare plans, measures and training facilities in anticipation of earthquake emergencies, which include rescue, relief and rehabilitation. International organizations compile databases containing ready-to-use scientific, technical and educational tools (STEND, 1996).

Public awareness: Programmes to inform the public on earthquake risk are prepared with the participation of governments, local authorities, and the mass media including scenarios and disaster simulation

5.2 DESCRIPTION OF EARTHQUAKE HAZARDS

An earthquake is caused by the abrupt release of gradually accumulated strain energy along a fault or zone of fracturing within the earth's crust. When a fault ruptures seismic waves are propagated in all directions from the source. As the waves hit the surface of the earth, they can cause a variety of physical phenomena and associated hazards. Each of these hazards can cause damage to buildings, facilities and lifelines systems. Table 5 1 lists the major earthquakes since 1990 that have resulted in more than one thousand deaths. In general, the effects of earthquakes at the ground surface may be classified into the following domains:

— permanent rupturing (faults, fissures, etc.);
— transient shaking (frequency, amplitude, duration, etc.);
— permanent deformation (folds, settlements, etc.);
— induced movement (liquefaction, landslides, etc).

Other common effects of earthquakes are fires and floods. Aftershocks, usually following an already disastrous earthquake, often cause additional damage by reactivating any or all of these physical phenomena.

As a consequence of the intensity, spectral content and duration of the ground shaking, buildings and lifeline systems (depending on their geometry) are forced to vibrate in the vertical and horizontal directions. Extensive damage takes place if the structures are not designed and built to withstand the permanent displacements and dynamic forces resulting from earthquake motions.

Evaluation of earthquake hazards and associated risks is a complex task (Hays, 1990) Scientists and engineers must perform a wide range of technical analyses that are conducted on different scales. Regional studies establish the physical parameters needed to define the earthquake potential of a region. Local studies define the dominant physical parameters that control the site-specific characteristics of the hazard. In principle, all of the studies seek answers to the following technical questions:

- Where are the earthquakes occurring now?
- Where did they occur in the past?
- Why are they occurring?
- How often do earthquakes of a certain size (magnitude) occur?
- How big (severe) have the physical effects been in the past?
- How big can they be in the future?
- How do the physical effects vary in space and time?

The size or severity of an earthquake is usually expressed by two well-established quantities: magnitude and (epicentral) intensity. Magnitudes are determined from instrumental recordings (seismograms), scaled logarithmically

Table 5.1 — Earthquakes with 1 000 or more deaths from 1900 to 1990 (Source: NEIC, 1990)

Date	Location	Coordinates		Deaths	Magnitude Richter scale	Comments
16/12/1902	Turkestan	40 8 N	72.6 E	4 500	6.4	
04/04/1905	India, Kangra	33 0 N	76.0 E	19 000	8.6	
08/09/1905	Italy, Calabria	39.4 N	16.4 E	2 500	7 9	
31/01/1906	Colombia	1 N 81	5 W	1 000	8 9	
17/03/1906	Formosa	—	—	1 300	7 1	
17/08/1906	Chile, Santiago	33 S	72 W	20 000	8 6	
14/01/1907	Jamaica	18.2 N	76.7 W	1 600	6 5	
21/10/1907	Central Asia	38 N	69 E	12 000	8.1	
28/12/1908	Italy, Messina	38 N	15.5 E	> 70 000	7.5	Death from earthquake and tsunami
09/08/1912	Marmara Sea	40.5 N	27 E	1 950	7.8	
13/01/1915	Italy, Avezzano	42 N	13.5 E	29 980	7.5	
16/12/1920	China, Gansu	35.8 N	105 7 E	200 000	8.6	Major fractures, landslides
01/09/1923	Japan, Kwanto	35.0 N	139 5 E	143 000	8.3	Great Tokyo fire
16/03/1925	China, Yunnan	25.5 N	100 3 E	5 000	7.1	
07/03/1927	Japan, Tango	35.8 N	134.8 E	3 020	7.9	
22/05/1927	China, Xining	36.8 N	102.8 E	200 000	8 3	Large fractures
01/05/1929	Islamic Republic of Iran	38 N	58 E	3 300	7.4	
23/07/1930	Italy	41.1 N	15.4 E	1 430	6.5	
25/12/1932	China, Gansu	39.7 N	97.0 E	70 000	7.6	
02/03/1933	Japan, Sanriku	39 0 N	143.0 E	2 990	8.9	
15/01/1934	Bihar-Nepal	26 6 N	86.8 E	10 700	8.4	
20/04/1935	Formosa	24.0 N	121 0 E	3 280	7.1	
30/05/1935	Pakistan, Quetta	29.6 N	66 5 E	> 30 000	7.5	Quetta almost completely destroyed
25/01/1939	Chile, Chillan	36 2 S	72.2 W	28 000	8.3	
26/12/1939	Turkey, Erzincan	39.6 N	38 E	30 000	8.0	
10/09/1943	Japan, Tottori	35.6 N	134.2 E	1 190	7 4	
07/12/1944	Japan, Tonankai	33.7 N	136.2 E	1 000	8 3	
12/01/1945	Japan, Mikawa	34.8 N	137.0 E	1 900	7.1	
31/05/1946	Turkey	39.5 N	41.5 E	1 300	6 0	
10/11/1946	Peru, Ancash	8 3 S	77.8 W	1 400	7.3	Landslides, great destruction
20/12/1946	Japan, Tonankai	32 5 N	134 5 E	1 330	8.4	
28/06/1948	Japan, Fukui	36 1 N	136.2 E	5 390	7.3	
05/08/1949	Ecuador, Ambato	1 2 S	78 5 E	6 000	6.8	Large landslides, topographical changes
15/08/1950	Assam, Tibet	28 7 N	96 6 E	1 530	8.7	Great topographical changes, landslides, floods
09/09/1954	Algeria	36 N	1.6 E	1 250	6 8	
02/07/1957	Islamic Republic of Iran	36.2 N	52.7 E	1 200	7 4	
13/12/1957	Islamic Republic of Iran	34.4 N	47.6 E	1 130	7.3	
29/02/1960	Morocco, Agadir	30 N	9 W	> 10 000	5 9	Occurred at shallow depth
22/05/1960	Chile	39.5 S	74 5 W	> 4 000	9.5	Tsunami, volcanic activity, floods
01/09/1962	Islamic Republic of Iran, Qazvin	35 6 N	49.9 E	12 230	7.3	
26/07/1963	Yugoslavia, Skopje	42 1 N	21.4 E	1 100	6.0	Occurred at shallow depth
19/08/1966	Turkey, Varto	39 2 N	41.7 E	2 520	7.1	
31/08/1968	Islamic Republic of Iran	34 0 N	59.0 E	> 12 000	7.3	
25/07/1969	Eastern China	21.6 N	111 9 E	3 000	5.9	
04/01/1970	China, Yunnan	24.1 N	102.5 E	10 000	7.5	
28/03/1970	Turkey, Gediz	39.2 N	29 5 E	1 100	7.3	
31/05/1970	Peru	9 2 S	78 8 W	66 000	7 8	Great rock slide, floods
10/04/1972	Islamic Republic of Iran	28.4 N	52.8 E	5 054	7.1	
23/12/1972	Nicaragua, Managua	12.4 N	86.1 W	5 000	6.2	
06/09/1975	Turkey	38.5 N	40 7 W	2 300	6.7	
04/02/1976	Guatemala	15 3 N	89.1 W	23 000	7.5	
06/05/1976	Italy, northeastern	46 4 N	13.3 E	1 000	6.5	
25/06/1976	Papua New Guinea	4.6 S	140.1 E	422	7.5	> 9 000 missing and presumed dead
27/07/1976	China, Tangshan	39.6 N	118 0 E	255 000	8.0	
16/08/1976	Philippines, Mindan	6.3 N	124 0 E	8 000	7.9	
24/11/1976	Islamic Republic of Iran, northwest	39 1 N	44.0 E	5 000	7.3	
04/03/1977	Romania	45 8 N	26.8 E	1 500	7 2	
16/09/1978	Islamic Republic of Iran	33.2 N	57 4 E	15 000	7.8	
10/10/1980	Algeria, El Asnam	36.1 N	1.4 E	3 500	7.7	
23/11/1980	Italy, southern	40.9 N	15.3 E	3 000	7.2	
11/06/1981	Islamic Republic of Iran, southern	29.9 N	57.7 E	3 000	6.9	
28/07/1981	Islamic Republic of Iran, southern	30.0 N	57.8 E	1 500	7.3	
13/12/1982	W. Arabian Peninsula	14.7 N	44.4 E	2 800	6.0	
30/10/1983	Turkey	40.3 N	42 2 E	1 342	6.9	
19/09/1985	Mexico, Michoacan	18 2 N	102.5 W	9 500	8.1	
10/10/1986	El Salvador	13.8 N	89.2 W	1 000+	5 5	
06/03/1987	Colombia–Ecuador	0.2 N	77.8 W	1 000+	7 0	
20/08/1988	Nepal to India	26 8 N	86.6 E	1 450	6.6	
07/12/1988	Turkey–USSR	41.0 N	44 2 E	25 000	7 0	
20/06/1990	Islamic Republic of Iran, western	37.0 N	49.4 E	> 40 000	7 7	
16/07/1990	Philippines, Luzon	15.7 N	121.2 E	1 621	7 8	

to represent the total energy release in the earthquake focus. In general, this scale is called Richter scale, but it should be noted that different magnitude scales are in use by specialists. If not stated otherwise, the term magnitude simply refers to the Richter scale throughout this chapter.

On the other hand, the felt or damaging effects of an earthquake can also be used for scaling the size of an earthquake. This scale is called seismic intensity scale, sometimes also referred to as the Mercalli scale after one of the early authors. It is common in most countries of the world to use 12 grades of intensity, expressed with the Roman numerals I to XII. Japan is an exception and uses a 7-grade intensity scale. The maximum intensity of an earthquake, usually found in the epicentral areas, is called the epicentral intensity, and replaces or complements the magnitude when describing the size of historical earthquakes in catalogues.

For earthquakes with relatively shallow focal depths (about 10 km), the following approximate empirical relationship holds:

Magnitude (Richter)	*Epicentral intensity*	*Magnitude (Richter)*	*Epicentral intensity*
(<3)	I	5	VII
	II	5.5	VIII
3	III	6	IX
3.5	IV		X
4	V	(>6)	XI
4.5	VI		XII

5.3 CAUSES OF EARTHQUAKE HAZARDS

5.3.1 Natural seismicity

The concept of large lithospheric plates migrating on the earth's surface allows deep insight into earthquake generation on a global scale. This has become known as plate tectonics. Three plate boundary related mechanisms can be identified through which more than 90 per cent of the earth's seismicity is produced These are:

(*a*) Subduction zones in which deep focus earthquakes are produced in addition to the shallow ones (e.g., west coast of South America, Japan);

(*b*) Midocean ridges with mainly shallow earthquakes, which are often connected with magmatic activities (e g , Iceland, Azores); and

(*c*) Transform faults with mainly shallow seismicity (e.g., west coast of North America, northern Turkey).

In general, shallow-focus earthquake activity contributes much more to the earthquake hazard in an area than the less frequently occurring deep earthquake activity. However, deep strong earthquakes should not be neglected in complete seismic hazard calculations Sometimes they even may dominate the seismic hazard at intermediate and larger distances from the active zone, as found, for example, in Vrancea, Romania.

A smaller portion of the world's earthquakes occur within the lithosphere plates away from the boundaries. These "intra-plate" earthquakes are important and sometimes occur with devastating effects. They are found in the eastern USA, northern China, central Europe and western Australia

5.3.2 Induced seismicity

Reservoir-induced seismicity is observed during periods when hydroelectric reservoirs are being filled (Gough, 1978). About 10–20 per cent of all large dams in the world showed some kind of seismicity either during the first filling cycle or later when the change of the water level exceeded a certain rate. A significant number of prominent cases are described in the literature. Table 5.2 provides a sampling of such occurrences However, many other large reservoirs similar in size and geologic setting to the ones listed in Table 5.1 have never shown any noticeable seismic activity other than normal natural seismicity.

Mining-induced seismicity is usually observed in places with quickly progressing and substantial underground mining activity. The magnitudes of some events have been remarkable (Richter magnitude > 5), resulting in substantial damage in the epicentral area This type of seismicity is usually very shallow and the damaging effect is rather local. Examples of regions with well-known induced seismic activity are in South Africa (Witwaterstrand) and central Germany (Ruhrgebiet).

Explosion-induced seismic activity of the chemical or nuclear type is reported in the literature, but this type of seismicity is not taken into account for standard seismic hazard assessment.

Location	*Dam Height (m)*	*Capacity (km^3)*	*Year of impounding*	*Year of largest event*	*Strongest event Magnitude (Richter)*
Hoover, USA	221	38.3	1936	1939	5.0
Hsinfengkiang, China	105	11.5	1959	1961	6.1
Monteynard, France	130	0.3	1962	1963	4.9
Kariba, Zambia/Zimbabwe	128	160	1958	1963	5 8
Contra, Switzerland	230	0.1	1964	1965	5.0
Koyna, India	103	2.8	1962	1967	6.5
Benmore, New Zealand	110	2.1	1965	1966	5.0
Kremasta, Greece	160	4.8	1965	1966	6.2
Nurek, Tajikistan	300	10.5	1972	1972	4.5

Table 5.2 — Selected cases of induced seismicity at hydroelectric reservoirs

5.4 CHARACTERISTICS OF EARTHQUAKE HAZARDS

5.4.1 Application

Dynamic ground shaking and permanent ground movement are the two most important effects considered in the analysis of seismic hazard, at least with respect to buildings and lifelines. Dynamic ground shaking is the important factor for buildings. Permanent ground movements such as surface fault rupture, liquefaction, landslide, lateral spreading, compacting and regional tectonic deformation are typically more important than ground shaking with regard to extended lifeline systems. In summary, the following effects of strong earthquakes must be quantitatively investigated for standard seismic hazard and risk evaluations

5.4.2 Ground shaking

Ground shaking refers to the amplitude, frequency content and duration of the horizontal and vertical components of the vibration of the ground produced by seismic waves arriving at a site, irrespective of the structure or lifeline systems at that site. The frequency range of interest for buildings and engineered structures is generally 0.1–20 Hertz, although higher frequencies may be important for components of lifelines such as switches and distribution nodes in electrical power stations. Ground shaking will cause damage to structures, facilities and lifeline systems unless they are designed and constructed to withstand the vibrations that coincide with their natural frequencies.

The damages or other significant effects observed either at the epicentre (usually the location of maximum effects for that earthquake) or at locations distant to the epicentre are often used for the specification of ground motion in terms of seismic intensity grades. This is the preferred procedure for areas where no instrumental data are indicated in the catalogues of historical earthquakes. Caution in comparing intensity data of different origin has to be exercised, as various intensity scales are currently in use in different parts of the world (see 5.11).

The spatial, horizontal and vertical distribution of ground motions are very important considerations for extended lifeline systems. Spectral velocity and displacement are more significant values than peak acceleration for some structures such as bridges and pipelines. Ground shaking can also trigger permanent ground deformation. Buried pipelines are especially sensitive to these displacement-controlled processes rather than to the force-controlled process of ground shaking, which have the most pronounced effect on buildings.

The estimation of ground motion and ground shaking is sometimes considered important for the design of underground structures. However, seismological measurements show that the intensity of the ground shaking decreases with increasing depth from the surface, while permanent ground motion is the dominating parameter of concern.

5.4.3 Surface faulting

Surface faulting is the offset or rupturing of the ground surface by differential movement across a fault during an earthquake. This phenomenon is typically limited to a linear zone along the surface. Only a small fraction of earthquakes cause surface faulting Faulting tends to occur when the earthquake has a shallow focus (5–10 km depth) and is relatively strong (magnitude larger than Richter 6). Although a spectacular feature, the direct effect of faulting does not play a major role in hazard mapping due to its very local nature.

5.4.4 Liquefaction

Liquefaction is a physical process generated by vibration during strong earthquakes and is generally restricted to distinct localities leading to ground failure. Liquefaction normally occurs in areas predominated by clay to sand sized particles and high groundwater levels. Persistant shaking increases pore water pressure and decreases the shear strength of the material, resulting in rapid fluidization of the soil. Liquefaction causes lateral spreads, flow failures and loss of bearing strength. Although uncommon, liquefaction can occur at distances of up to 150 km from the epicentre of an earthquake and may be triggered by levels of ground shaking as low as intensity V or VI (12-grade intensity scale). A recent example of strong liquefaction was observed in the Kobe (Japan) earthquake of 1995 (EERI, 1995).

5.4.5 Landslides

Landslides can be triggered by fairly low levels of ground motion during an earthquake if the slope is initially unstable. The most abundant types of earthquake-induced landslides are rock falls and slides of rock fragments that form on steep slopes. The lateral extent of earthquake induced landslides reaches from a few metres to a few kilometres depending on the local geological and meteorological conditions. Landslides may produce large water waves if they slump into filled reservoirs, which may result in the overtopping of the dam. Although not as a result of an earthquake, a landslide on 9 October 1963 caused the overtopping of the Vajont dam, flooding Longarone and other villages in Italy. The flooding resulted in approximately 2 000 deaths.

Large earthquake-induced rock avalanches, soil avalanches and underwater landslides can be very destructive. One of the most spectacular examples occurred during the 1970 Peruvian earthquake when a single rock avalanche triggered by the earthquake killed more than 18 000 people The 1959 Hebgen Lake, Montana, earthquake triggered a similar but less spectacular landslide that formed a lake and killed 26 people.

5.4.6 Tectonic deformation

Deformation over a broad geographic area covering thousands of square kilometres is a characteristic feature of earthquakes having large magnitudes. In general, the following effects can be observed in principle and have to be recognized in seismic hazard assessment for specific sites:

(*a*) tilting, uplifting, and down warping;
(*b*) fracturing, cracking, and fissuring,
(*c*) compacting and subsidence;
(*d*) creeping in fault zones.

5.5 TECHNIQUES FOR EARTHQUAKE HAZARD ASSESSMENT

5.5.1 Principles

Objective of earthquake hazard assessment
The objective of a statistical earthquake hazard analysis is to assess the probability that a particular level of ground motion (e.g., peak acceleration) at a site is reached or exceeded during a specified time interval (such as 100 years). An alternative approach is to consider the evaluation of the ground motion produced by the maximum conceivable earthquake in the most unfavourable distance to a specific site.

Limits of earthquake hazard assessment
Earthquake hazard assessment in areas of low seismicity is much more subject to large errors than in areas with high earthquake activity. This is especially the case if the time span of the available data is considerably smaller than the mean return interval of large events, for which the hazard has to be calculated.

Incorporation of uncertainties
Uncertainties result from lack of data or/and lack of knowledge. In seismic hazard computations, the uncertainties of the basic input data must be taken into account (McGuire, 1993). This task is accomplished by developing alternative strategies and models in the interpretation of those input data, for which significant uncertainties are known to exist. This applies in particular for:

(*a*) the size, location, and time of occurrence of future earthquakes; and
(*b*) the attenuation of seismic waves as they propagate from all possible seismic sources in the region to all possible sites.

5.5.2 Standard techniques

Input models for probabilistic seismic hazard analysis:

(a) Earthquake source models
The identification and delineation of seismogenic sources in the region is an important step in preparing input parameters for hazard calculation. Depending on the quality and completeness of the basic data available for this task, these sources may have different shapes and characteristics.

Faults are line sources specified by their three-dimensional geometry — slip direction, segmentation and possible rupture length. A line source model is used when earthquake locations are constrained along an identified fault or fault zone. All future earthquakes along this fault are expected to have the same characteristics. A set of line sources is used to model a large zone of deformation where earthquake rupture has a preferred orientation but a random occurrence.

Area sources must be defined, if faults cannot be identified or associated to epicentres. Seismicity is assumed to occur uniformly throughout an area. An area source encompassing a collection of line sources is used when large events are assumed to occur only on identified active faults and smaller events are assumed to occur randomly within the region.

The existing distribution of earthquakes and the seismotectonic features can be represented by more than one possible set of source zones leading to quite different hazard maps for the same region (Mayer-Rosa and Schenk, 1989; EPRI, 1986).

(b) Occurrence models
For each seismic source (fault or area), an earthquake occurrence model must be specified. It is usually a simple cumulative magnitude (or intensity) versus frequency distribution characterized by a source-specific b-value and an associated activity rate. Different time of occurrence models such as Poissonian, time-predictable, slip-predictable and renewal have been used in the calculation process. Poissonian models are easy to handle but do not always represent correctly the behaviour of earthquake occurrence in a region. For the more general application, especially where area sources are used, the simple exponential magnitude model and average rate of occurrence are adequate to specify seismicity (McGuire, 1993).

It must be recognized that the largest earthquakes in such distributions sometimes occur at a rate per unit time that is larger than predicted by the model. A "characteristic" earthquake distribution is added to the exponential model to account for these large events.

(c) Ground motion models
The ground motion model relates a ground motion parameter to the distance from the source(s) and to the size of the earthquake. The choice of the type of ground motion parameter depends on the desired seismic hazard output. Usual parameters of interest are peak ground acceleration (PGA), peak ground velocity (PGV) and spectral velocity for a specified damping and frequency. Effective maximum acceleration is used as a parameter when large scatter of peak values is a problem. All these parameters can be extracted from accelerograms, which are records produced by specific instruments (accelerometers) in the field.

In cases where the primary collection of earthquakes consists of pre-instrumental events for which seismic intensities have been evaluated (see section 5.4.2), the site intensity (specified for example either by the EMS or MMI scale) is the parameter of choice for the representation of the ground motion level However, this method includes high uncertainties and bias due to the subjectiveness of intensity estimation in general. Furthermore, information on ground motion frequency is not explicitly considered within such models.

A preferred procedure in many countries to predict physical ground motion parameters at sites of interest is to convert the original intensity information into magnitude values and to use deterministic attenuation relations for acceleration and distance.

Seismic hazard calculation

The following two approaches of probabilistic hazard calculation are frequently applied:

(1) The deductive method uses statistical interpretations (or extrapolations) of the original data to describe the occurrence of earthquakes in time and space and their general characteristics. Cornell (1968) developed the method, while Algermissen and Perkins (1976) and McGuire (1976) wrote its computer codes. Hays (1980) and Basham and Giardini (1993) describe the procedure. The handling of uncertainties is contained in McGuire (1993). All steps from the collection of the basic data to the application of the method is shown schematically in Figure 5.1.

(2) The historic method directly uses the historical record of earthquakes and does not involve the definition of distinct seismic sources in form of faults and areas (Veneziano *et al.*, 1984). Each historical event is treated as a source for which the effect on the site is calculated individually. Seismic hazard is assessed by summation of the effects of all historical events on the site.

In both approaches, the probability of exceedance or non-exceedance of a certain level of ground motion for a given exposure time is the target result, considering earthquakes of all possible magnitudes and distances having an influence on the site.

Application of the deductive method

Step 1: Definition of seismogenic sources

Faults and area sources have to be delineated describing the geometric (3-dimensional) distribution of earthquake occurrence in the investigated area. Then distance and magnitude distributions

$$f_R(r) \quad \text{and} \quad f_M(m) \tag{5.1}$$

are calculated, with hypocentral distance (r) and magnitude (m).

Step 2: Definition of seismicity parameters

It is assumed that the rate of recurrence of earthquakes in general follows the Gutenberg-Richter (G-R) relation

$$\log_{10} n(m) = a - bm \tag{5.2}$$

where n(m) is the mean number of events per year having magnitudes greater than m, while a and b are constants defined by regression analysis as described in 5.5.2b above. For a single source, the modified G-R relation for the annual mean rate of occurrence is

$$n_o = a_N\left[1-\frac{1-e^{-b(m-m_l)}}{1-e^{-b(m_u-m_l)}}\right] \tag{5.3}$$

where m_u and m_l are the upper- and lower-bound magnitudes, and a_N is the number of events per year in the source having magnitudes m equal to or greater than m_l.

Step 3: Establishing the ground motion model

The ground motion equation is calculated for the conditional probability of A exceeding a* given an earthquake of magnitude m occurring at a distance r from a site

$$G(A > a^* \mid m, r) \tag{5.4}$$

where A and a* are ground motion values (acceleration).

Step 4: Probability analysis

The contribution of each source to the seismic hazard at the site is calculated from the distributions of magnitude, distance and ground motion amplitude. Following equations 5.1 to 5.4, the probability that the value A of ground motion at the site exceeds a specified level a* is:

$$P\left(A > a^*\right) = \sum_i n_o \iint G\left(A > a^* \mid m, r\right) f_m(m)\, f_R(r)\, dm\, dr \tag{5.5}$$

in which the summation is performed over all sources i, where n_o is the mean annual rate of occurrence for a source.

5.5.3 Refinements to standard techniques

Study of paleoseismicity

Field techniques have been developed to determine the dates of prehistoric earthquakes on a given fault and to extend the historical seismicity back in time as much as 10 000 years or more. These techniques involve trenching and age dating of buried strata that immediately pre-date and post-date a historic earthquake. The application of these techniques is called a "paleoseismicity" study (Pantosti and Yeats, 1993).

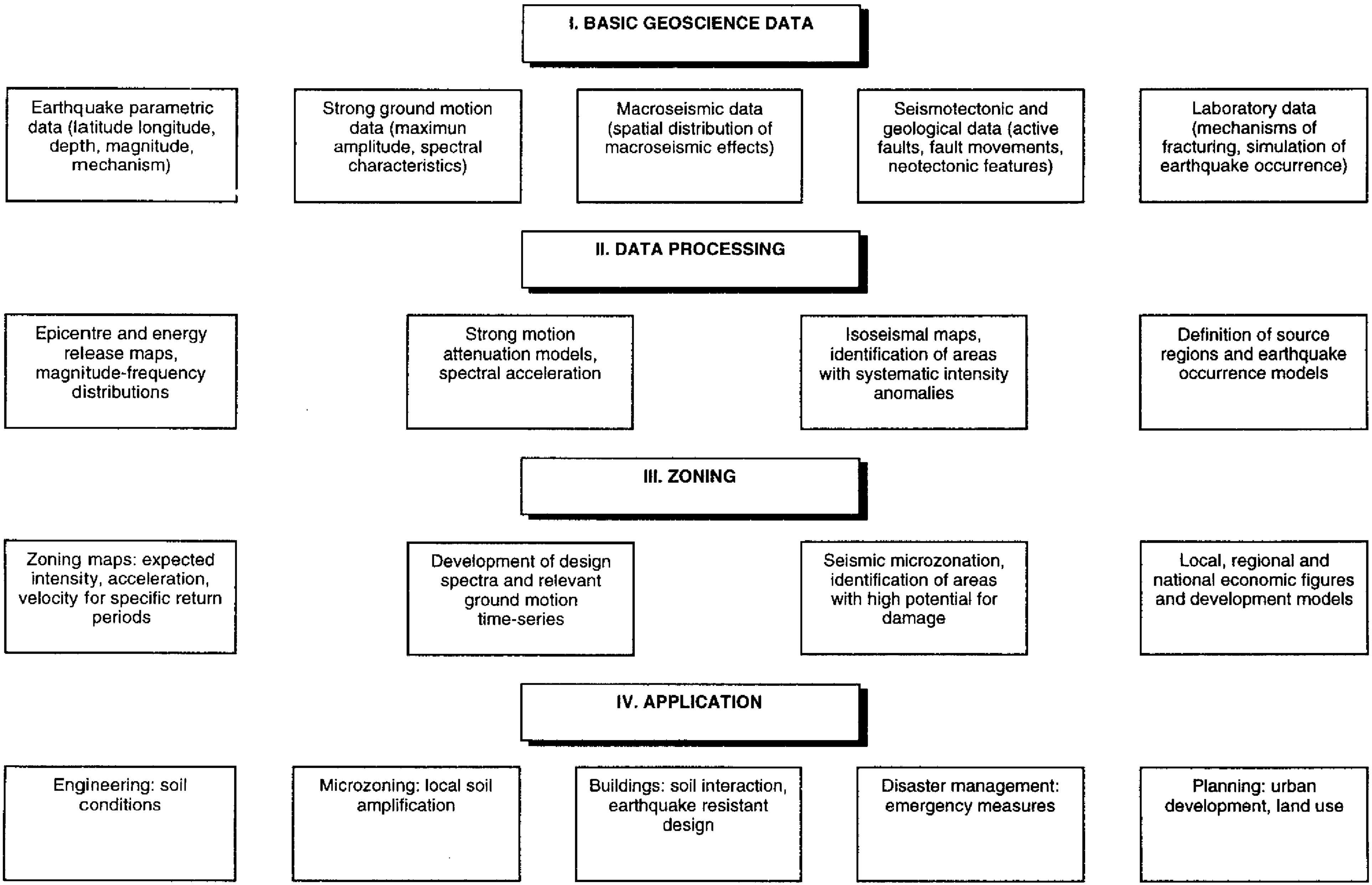
Study of site amplification

These studies help to quantify the spatial variation of ground shaking susceptibility and, thus, more precisely define the engineering design parameters. Experience and data have shown that strong contrasts in the shear-wave velocity between the near-surface soil layers and underlying bedrock can cause the ground motion to be amplified in a narrow range of frequencies, determined by the thickness of the soft layers. All relevant parameters, such as peak amplitudes, spectral composition and duration of shaking, are significantly changed when the velocity contrast exceeds a factor of about 2 and the thickness of the soil layer is between 10 and 200 m. Microzonation studies have been performed for a number of large cities in the world (Petrovski, 1978).

Study of the potential for liquefaction and landslides

Liquefaction is restricted to certain geologic and hydrologic conditions. It is mainly found in areas where sands and silts were deposited in the last 10 000 years and the ground water levels are within the uppermost 10 m of the ground. As a general rule, the younger and looser the sediment and the

Figure 5.1 – Schematic diagram of the steps (I-IV) and basic components of probabilistic earthquake hazard assessment



higher the water table, the more susceptible a clay to sandy soil will be to liquefaction.

Liquefaction causes three types of ground failures: lateral spreads, flow failures and loss of bearing strength. Liquefaction also enhances ground settlement. Lateral spreads generally develop on gentle slopes (< 3 degrees) and typically have horizontal movements of 3–5 m. In slope terrain and under extended duration of ground shaking the lateral spreads can be as much as 30–50 m.

5.5.4 Alternative techniques

Although the deductive methods in seismic hazard assessment are well established other methods may also give useful results under special conditions. These include historical and determinate approaches, described below.

The historical methods

In contrast to the deductive seismic source methods, nonparametric methods are often employed when the process of earthquake generation is not well known, or the distribution of historical earthquakes do not show any correlation with mapped geological features.

A historical method (Veneziano *et al.*, 1984) is based only on historical earthquake occurrence and does not make use of interpretations of seismogenic sources, seismicity parameters and tectonics. The method has limitations when seismic hazard for large mean return periods, i.e. larger than the time span of the catalogues, are of interest. The results have large uncertainties. In general, to apply the historical method, the following steps have to be taken:

(*a*) Compilation of a complete catalogue with all historic events including date, location, magnitude, and/or intensity and uncertainties (Stucchi and Albini, 1991; Postpischl, 1985).
(*b*) Development of an attenuation model that predicts ground motion intensity as a function of distance for a complete range of epicentral intensities or magnitudes. Uncertainties are introduced in the form of distributions representing the dispersion of the data.
(*c*) Calculation of the ground motion produced by each historical earthquake at the site of interest. The summation of all effects is finally represented in a function relating the frequency of occurrence with all ground motion levels.
(*d*) Specification of the annual rate of exceedance by dividing this function through the time-span of the catalogue. For small values of ground motion the annual rate is a good approximation to the annual probability of exceedance.

The deterministic approach

Deterministic approaches are often used to evaluate the ground-shaking hazard for a selected site. The seismic design parameters are resolved for an *a priori* fixed earth quake that is transposed onto a nearby tectonic structure, nearest to the building, site or lifeline system. An often-applied procedure includes the following steps:

(*a*) Choosing the largest earthquake that has occurred in history or a hypothetical large earthquake whose occurrence would be considered plausible in a seismogenic zone in the neighbourhood of the site.
(*b*) Locating this earthquake at the nearest possible point within the zone, or on a fault.
(*c*) Adoption of an empirical attenuation function for the desired ground motion parameter, preferably one based on local data, or at least taken from another seismotectonically similar region.
(*d*) Calculation of the ground motion at the site of interest for this largest earthquake at the closest possible location.
(*e*) Repetition for all seismotectonic zones in the neighbourhood of the site and choice of the largest calculated ground motion value.

Estimations of seismic hazard using this method usually are rather conservative. The biggest problem in this relatively simple procedure is the definition of those critical source boundaries that are closest to the site and, thus, define the distance of the maximum earthquake. Deterministic methods deliver meaningful results if all critical parameters describing the source-path-site-system are sufficiently well known.

5.6 DATA REQUIREMENTS AND SOURCES

The ideal database, which is never complete and/or available for all geographic regions in the world, should contain the information for the area under investigation (Hays, 1980) as outlined in this section. This database corresponds to the components under "Basic Geoscience Data" in Figure 5.1.

5.6.1 Seismicity data

These data include complete and homogeneous earthquake catalogues, containing all locations, times of occurrence, and size measurements of earthquakes with fore- and aftershocks identified. Uniform magnitude and intensity definitions should be used throughout the entire catalogue (Gruenthal, 1993), and uncertainties should be indicated for each of the parameters.

5.6.2 Seismotectonic data

The data include maps showing the seismotectonic provinces and active faults with information about the earthquake potential of each seismotectonic province, including information about the geometry, amount and sense of movement, temporal history of each fault, and the correlation with historical and instrumental earthquake epicentres. The delineation of seismogenic source zones depends strongly on these data.

5.6.3 Strong ground motion data

These data include acceleration recordings of significant earthquakes that occurred in the region or have influence on the site. Scaling relations and their statistical distribution for ground-motion parameters as a function of distance have to be developed for attenuation models.

5.6.4 Macroseismic data

These data include macroseismic observations and isoseismal maps of all significant historical earthquakes that have affected the site. Relationships between macroseismic observations (intensities) and physical ground motion measurements (accelerations) have to be established

5.6.5 Spectral data

Adequate ensembles of spectra are required for "calibrating" the near field, the transmission path, and the local-ground response. Thus, frequency dependent anomalies in the spatial distribution of ground motions can be identified and modelled

5.6.6 Local amplification data

These data describe seismic wave transmission characteristics (amplification or damping) of the unconsolidated materials overlying bedrock and their correlation with physical properties including seismic shear wave velocities, densities, shear module and water content. With these data, microzonation maps can be developed in local areas identifying and delineating anomalous amplification behaviour and higher seismic hazards.

5.7 ANTHROPOGENIC FACTORS

The factors that continue to put the world's population centres at risk from earthquake hazards are:
- rapid population growth in earthquake-prone areas;
- growing urban sprawl as a worldwide phenomenon,
- existence of large numbers of unsafe buildings, vulnerable critical facilities and fragile lifelines; and
- interdependence of people in local, regional, national and global communities.

5.8 PRACTICAL ASPECTS

The earthquake database used in seismic hazard assessment as a basic input usually consists of an instrumentally determined part and a normally much larger historical time span with macroseismically determined earthquake source data.

It is essential to evaluate the historical (macroseismic) part of the data by using uniform scales and methods. For the strongest events, well-established standard methods must be applied (Stucchi and Albini, 1991; Guidoboni and Stucchi, 1993). Special care must be taken whenever catalogues of historical earthquakes of different origin are merged, e g , across national borders

The total time span of earthquake catalogues can vary from some tens to some thousands of years. In general, the earthquake database is never homogeneous with respect to completeness, uniform magnitude values or location accuracy. The completeness of catalogues must be assessed in each case and used accordingly to derive statistical parameters such as the gradient of log frequency-magnitude relations.

It is inevitable that one has to extrapolate hazard from a more or less limited database. The results of hazard calculations are, therefore increasingly uncertain as larger mean recurrence periods come into the picture. This is especially so, if these periods exceed the entire time window of the underlying earthquake catalogue. The user of the output of seismic hazard assessments should be advised about the error range involved in order to make optimal use of this information.

Different physical parameters for ground shaking may be used to describe seismic hazard These include peak acceleration, effective (average) acceleration, ground velocity, and the spectral values of these parameters. However, for practical and traditional reasons, the parameter selected most often for mapping purposes is horizontal peak acceleration (Hays, 1980)

5.9 PRESENTATION OF HAZARD ASSESSMENTS

5.9.1 Probability terms

With respect to hazard parameters, two equivalent results are typically calculated These are the peak acceleration corresponding to a specified interval of time, which is known as exposure time, or the peak acceleration having a specified average recurrence interval. Table 5 3 provides a few examples of these two methods of expressing hazard.

While recurrence intervals in the order of 100 to 500 years are considered mainly for standard building code applications, larger recurrence intervals of 1 000 years or more are chosen for the construction of dams and critical lifeline systems. Even lower probabilities of exceedance (e.g., 10 000 year recurrence interval or more or 1 per cent in 100 years or smaller) have to be taken into account for nuclear installations, although the life span of such structures may only be 30 to 50 years. Use is made of equation 6.1 to obtain the recurrence internal as listed in Table 5 3

5.9.2 Hazard maps

In order to show the spatial distribution of a specific hazard parameter, usually contoured maps of different scales are prepared and plotted. These maps may be classified into different levels of importance, depending on the required detail of information, as listed in Table 5.4. These scales are only approximate and may vary in other fields of natural hazards. Seismic hazard assessment on the local and project level usually incorporates the influence of the local geological conditions. The resulting hazard maps are presented then in the form of so-called "Microzoning" maps showing mainly the different susceptibility to ground shaking in the range of metres to kilometres.

Table 5.3 — Examples of equivalent hazard figures

Probability of exceedance for a given exposure time	Probability or non-exceedance for a given exposure time	Equivalent approximate average recurrence interval
10 per cent in 10 years	90 per cent in 10 years	100 years
10 per cent in 50 years	90 per cent in 50 years	500 years
10 per cent in 100 years	90 per cent in 100 years	1 000 years
1 per cent in 100 years	99 per cent in 100 years	10 000 years

Figure 5.2 shows a composite of different national seismic hazard maps. The parameter representing ground motion is intensity defined according to the new European Macroseismic Scale (Gruenthal, 1998). The probability of non-exceedance of the indicated intensities in this map is 90 per cent in 50 years, equivalent to a recurrence interval of exactly 475 years, which corresponds to the level required for the new European building codes-EC8. This map in an example for international normalization of procedures, since it was uniformly computed with the same criteria and assumptions for the three countries — Austria, Germany and Switzerland.

5.9.3 Seismic zoning

Zoning maps are prepared on the basis of seismic hazard assessment for providing information on expected earthquake effects in different areas. The zoned parameters are of a different nature according to their foreseen use. The following four types of zoning maps may serve as examples:

(*a*) maps of maximum seismic intensity, depicting the spatial distribution of the maximum observed damage during a uniform time period, mainly used for deterministic hazard assessment;

(*b*) maps of engineering coefficients and design parameters, mainly used for national building code specifications;

(*c*) maps of maximum expected ground motion (acceleration, velocity, displacement, etc.) for different recurrence intervals, including amplification factors for different ground conditions (microzonation maps); and

(*d*) maps of zones where different political and/or administrative regulations have to be applied with respect to earthquakes, mainly used for economic and/or logistic purposes.

Typical zoning maps are those used in earthquake-building codes (Sachanski, 1978) The specification and quantification of the different zones in terms of design parameters and engineering coefficients is demonstrated in the two maps for Canada shown in Figure 5.3 (Basham *et al.*, 1985). Shown are the peak ground motion values with 10 per cent probability of exceedance in 50 years, together with the zoning specifications. They differ in terms of the contoured type of the ground motion parameter, horizontal acceleration and horizontal velocity, respectively.

Table 5 4 — Level of importance and scales in seismic hazard mapping

Level	scale	Level	scale
National	1 1 000 000	Local	1 25 000
Regional	1 250 000	Project	1 5 000

5.10 PREPAREDNESS AND MITIGATION

There are basically three ways to reduce the risk imposed by earthquakes (Hays, 1990). They are:

(*a*) to reduce vulnerability of structures,

(*b*) to avoid high hazard zones; and

(*c*) to increase the awareness and improve the preparedness of the population.

The reduction of vulnerability is achieved most economically by applying established building codes. With the proven measures listed in such codes and developed for engineering practice, the desired level of protection can be achieved with a good benefit-cost ratio or the minimum expected life-cycle cost (Pires *et al.*, 1996; Ang and De Leon, 1996). Such building codes, either in rigid legal form or as a more flexible professional norm, are available in almost every civilized country in the world. However, the national codes of even neighbouring countries are often found to differ considerably, leading to discontinuities in the level of protection across national borders. For Europe a new uniform code, Eurocode 8, is expected to improve this situation in future.

One way to also reduce the financial consequences for the individual is by insurance (Perrenoud and Straub, 1978). However, the integral costs of a disastrous earthquake in a densely populated and industrialized area may well exceed the insured property value and may severely affect the economic health of a region. This is beyond aspects dealing with the human losses.

Disaster response planning and increasing preparedness for strong earthquakes may also reduce considerably the extreme effects of earthquakes. Preparedness on family, community, urban and national levels is crucial in earthquake-prone countries. Such preparedness plans have been developed in many countries.

Public education and increased awareness, through at times the involvement of the mass media, are very efficient tools in reducing risks on a personal level. Professional and educational efforts in schools and universities provide a solid basis for the transfer of knowledge (Jackson and Burton, 1978).

5 11 GLOSSARY OF TERMS

Accelerogram: The recording of an instrument called accelerometer showing ground motion acceleration as

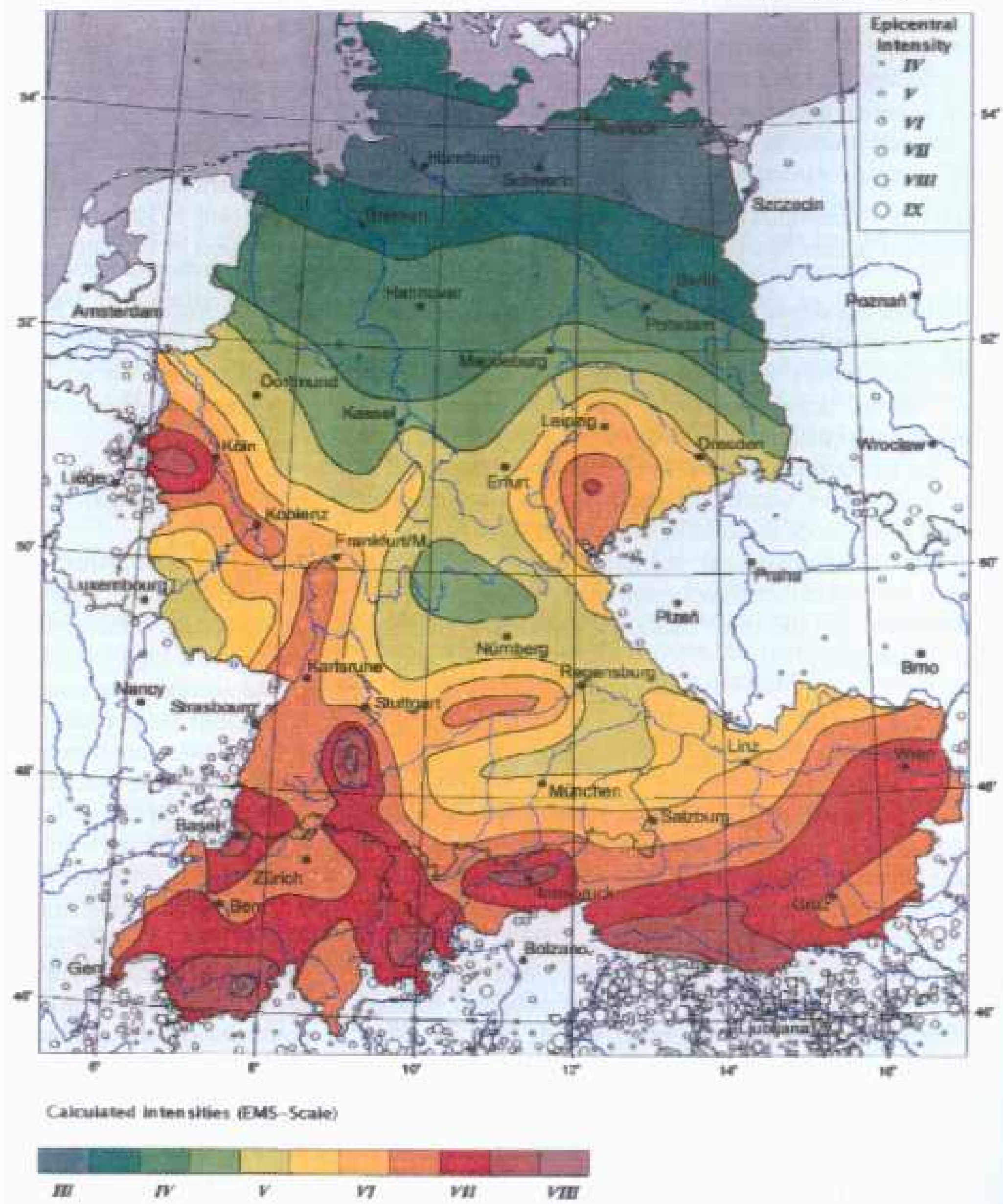


Figure 5.2 — Uniform seismic hazard map for Austria, Germany and Switzerland (Gruenthal et al., *1995). Ground motion parameter in seismic intensity (EMS-Scale), with a probability of 90 per cent not to be exceeded, or recurrence interval of 475 years*

a function of time. The peak acceleration is the largest value of acceleration on the accelerogram and very often used for design purposes.

Acceptable risk: A probability of occurrences of social or economic losses due to earthquakes that is sufficiently low so that the public can accept these consequences (e.g., in comparison to other natural or human-made risks). This risk is determined by authorities to represent a realistic basis for determining design requirements for engineered structures, or for taking certain social or economic actions.

Active fault: A fault is active if, because of its present tectonic setting, it can undergo movement from time to time in the immediate geologic future. Scientists have used a number of characteristics to identify active faults, such as historic seismicity or surface faulting, geological recent displacement inferred from topography or stratigraphy, or physical connection with an active fault. However, not enough is known of the behaviour of faults to assure identification of all active faults by such characteristics.

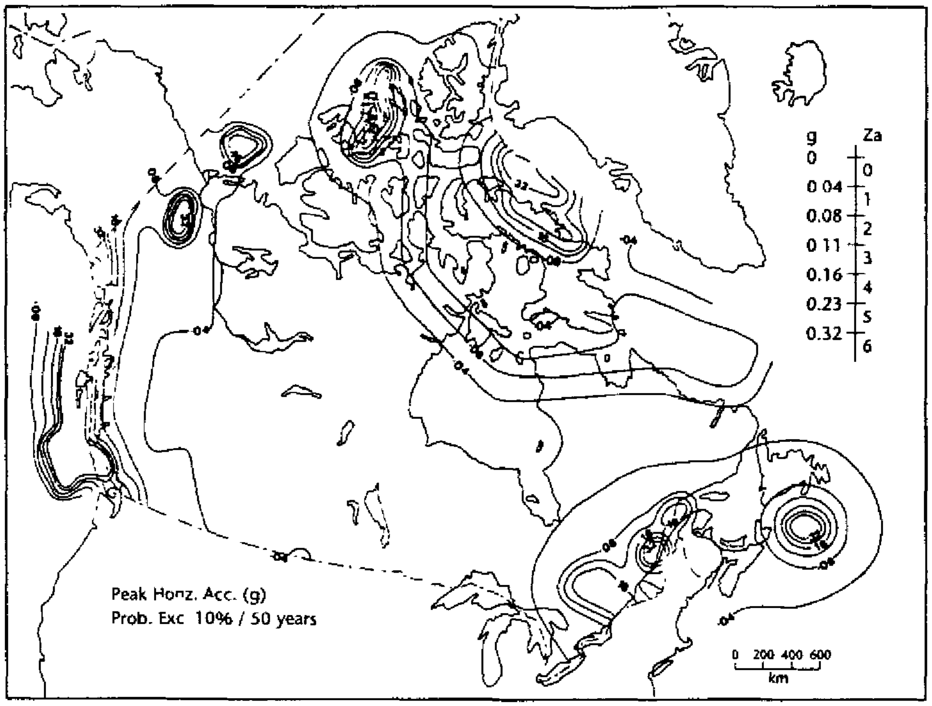
Attenuation: Decrease in seismic ground motion with distance. It depends generally on a geometrical spreading factor and the physical characteristics between source of energy and observation point or point of interest for hazard assessment.

b-value: A parameter in the Gutenberg-Richter relationship log $N = a - b * M$ indicating the relative frequency of earthquakes of different magnitudes, M, derived from historical seismicity data. Worldwide studies have shown that these b-values normally vary between 0.6 and 1.4.

Bedrock: Any solid, naturally occurring, hard consolidated material located either at the surface or underlying soil. Rocks have a shear-wave velocity of at least 500 m/s at small (0.0001 per cent) levels of strain.

Design earthquake: A specification of the ground motion at a site based on integrated studies of historic seismicity and structural geology and used for the earthquake-resistant design of a structure.

Design spectra: Spectra used in earthquake-resistant design which correlate with design earthquake ground motion values. A design spectrum is typically a spectrum



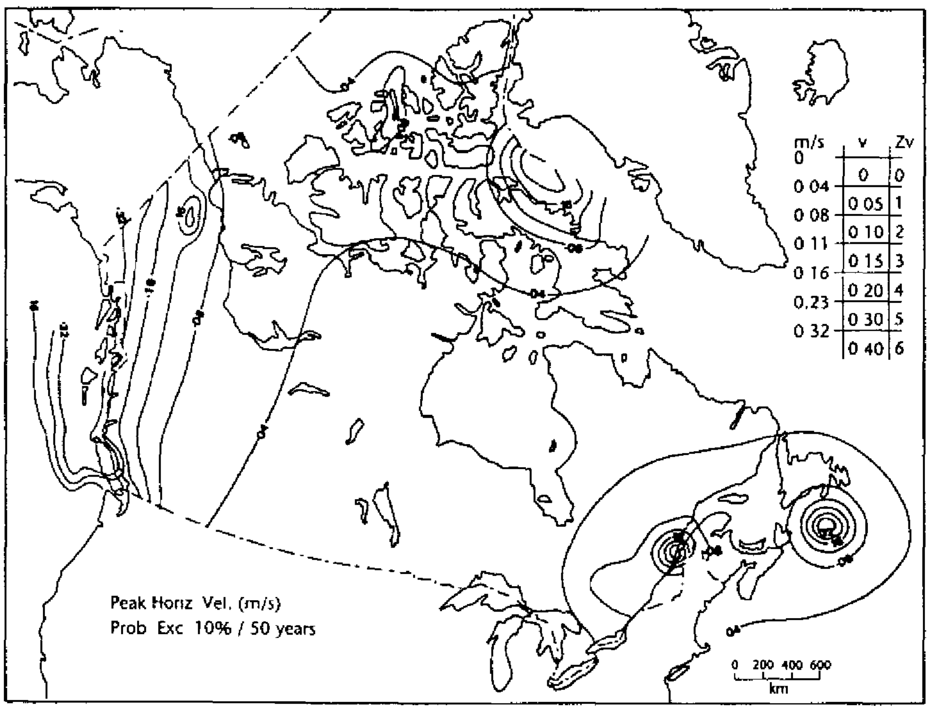


Figure 5 3 — Typical peak horizontal acceleration zoning map (above) and peak horizontal velocity zoning map (below) for the probability of exceedance of 10 per cent in 50 years, used in the new building code of Canada. Seven zones, Za and Zv, are contoured with units in fractions of gravity, g = 981 m/s2, and m/s, respectively (after Basham et al., *1985)*

having a broad frequency content. The design spectrum can be either site-independent or site-dependent. The site-dependent spectrum tends to be less broad band as it depends also on (narrow band) local site conditions.

Duration: A description of the length of time during which ground motion at a site exhibits certain characteristics such as being equal to or exceeding a specified level of acceleration (e.g., 0.05 g)

Earthquakes: Sudden release of previously accumulated stresses in the earth's crust and thereby producing seismic waves.

Earthquake hazards: Probability of occurrence of natural phenomena accompanying an earthquake such as ground shaking, ground failure, surface faulting, tectonic deformation, and inundation which may cause damage and loss of life during a specified exposure time (see also *earthquake risk*).

Earthquake risk: The social or economic consequences of earthquakes expressed in money or casualties. Risk is composed from hazard, vulnerability and exposure. In more general terms, it is understood as the probability of a loss due to earthquakes.

Earthquake waves: Elastic waves (body and surface waves) propagating in the earth, set in motion by faulting of a portion of the earth.

EMS-Scale 1998: Short form:

- I — *Not felt.*
- II — *Scarcely felt*, only by very few individuals at rest.
- III — *Weak*, felt indoors by a few people, light trembling.
- IV — *Largely observed*, felt indoors by many people, outdoors by very few. A few people are awakened. Windows, doors and dishes rattle.
- V — *Strong*, felt indoors by most, outdoors by few. Many sleeping people are woken up. A few are frightened Buildings tremble throughout. Hanging objects swing considerably. Small objects are shifted. Doors and windows swing open or shut.
- VI — *Slightly damaging*, many people are frightened and run outdoors. Some objects fall. Many houses suffer slight non-structural damage.
- VII — *Damaging*, most people are frightened and run outdoors. Furniture is shifted and objects fall from shelves in large numbers. Many well-built ordinary buildings suffer moderate damage Older buildings may show large cracks in walls and failure of fill-in walls.
- VIII — *Heavily damaging*, many people find it difficult to stand. Many houses have large cracks in walls. A few well-built ordinary buildings show serious failure of walls. Weak old structures may collapse.
- IX — *Destructive*, general panic. Many weak constructions collapse Even well-built ordinary buildings show very heavy damage, e.g., partial structural failure.
- X — *Very destructive*, many ordinary well-built buildings collapse.
- XI — *Devastating*, most ordinary well-built buildings collapse, even some with good earthquake resistant design.
- XII — *Completely devastating*, almost all buildings are destroyed.

Epicentre The point on the earth's surface vertically above the point where the first fault rupture and the first earthquake motion occur.

Exceedance probability: The probability (for example 10 per cent) over some exposure time that an earthquake will generate a value of ground shaking greater than a specified level.

Exposure time: The period of time (for example, 50 years) that a structure or facility is exposed to earthquake hazards. The exposure time is sometimes related to the design lifetime of the structure and is used in seismic risk calculations.

Fault: A fracture or fracture zone in the earth along which displacement of the two sides relative to one another has occurred parallel to the fracture. Often visible as fresh ground displacement at the earth's surface after strong, shallow events.

Focal depth: The vertical distance between the earthquake hypocentre and the earth's surface.

Ground motion: A general term including all aspects of motion; for example particle acceleration (usually given in fractions of the earth's gravitation (g) or in percentage of it), velocity or displacement. Duration of the motion and spectral contents are further specifications of ground motion. Ground acceleration, response spectra (spectral acceleration, velocity and displacement) and duration are the parameters used most frequently in earthquake-resistant design to characterize ground motion. Design spectra are broad-band and can be either site-independent (applicable for sites having a wide range of local geologic and seismologic conditions) or site-dependent (applicable to a particular site having specific geologic and seismological conditions).

Hertz. Unit of the frequency of a vibration, given in cycles per second.

Induced seismicity Generated by human activities mainly in mining and reservoir areas. Can produce considerable or even dominating hazards. There are two likely causes for the triggering effect of a large reservoir. The strain in the rock is increased by the extra load of the reservoir fill, and reaches the condition for local faulting. However, this theory is physically not as acceptable as the second one, which involves increased pore pressure due to infiltrated water, thereby lowering the shear strength of the rocks along existing fractures and triggering seismicity. The focal depths of reservoir-induced earthquakes are usually shallower than 10 km.

Intensity: A numerical index describing the effects of an earthquake on the earth's surface, on people and on structures. The scale in common use in the USA today is the Modified Mercalli Intensity (MMI) Scale of 1931. The Medvedev-Sponheuer-Karnik (MSK) Scale of 1964 is widely used in Europe and was recently updated to the new European Macroseismic (EMS) Scale in 1998. These scales have intensity values indicated by Roman numerals from I to XII. The narrative descriptions of the intensity values of the different scales are comparable and therefore the three scales roughly correspond. In Japan the 7-degree scale of the Japan Meteorological Agency (JMA) is used. Its total range of effects is the same as in the 12-degree scales, but its lower resolution allows for an easier separation of the effects.

Landslides: Refer to downward and outward movement on slopes of rock, soil, artificial fill and similar materials. The factors that control landsliding are those that increase the shearing stress on the slope and decrease the shearing strength of the earth materials. The latter is likely to happen in periods with large rainfalls.

Liquefaction: The primary factors used to judge the potential for liquefaction, the transformation of unconsolidated materials into a fluid mass, are: grain size, soil density, soil structure, age of soil deposit and depth to ground water. Fine sands tend to be more susceptible to liquefaction than silts and gravel. Behaviour of soil deposits during historical earthquakes in many parts of the world show that, in general, liquefaction susceptibility of sandy soils decreases with increasing age of the soil deposit and increasing depth to ground water. Liquefaction has the potential of occurring when seismic shear waves having high acceleration and long duration pass through a saturated sandy soil, distorting its granular structure and causing some of the void spaces to collapse. The pressure of the pore water between and around the grains increases until it equals or exceeds the confining pressure. At this point, the water moves upward and may emerge at the surface. The liquefied soil then behaves like a fluid for a short time rather than as a solid.

Magnitude: A quantity characteristic of the total energy released by an earthquake, as contrasted to intensity that describes its effects at a particular place. C.F. Richter devised the logarithmic scale for local magnitude (ML) in 1935. Magnitude is expressed in terms of the motion that would be measured by a standard type of seismograph located 100 km from the epicentre of an earthquake. Several other magnitude scales in addition to ML are in use; for example, body-wave magnitude (mb) and surface-wave magnitude (MS). The scale is theoretically open ended, but the largest known earthquakes have MS magnitudes slightly over 9.

Peak acceleration: The value of the absolutely highest acceleration in a certain frequency range taken from strong-motion recordings. Effective maximum acceleration (EMA) is the value of maximum ground acceleration considered to be of engineering significance. EMA is usually 20–50 per cent lower than the peak value in the same record. It can be used to scale design spectra and is often determined by filtering the ground-motion record to remove the very high frequencies that may have little or no influence on structural response.

Plate tectonics: Considered as the overall governing process responsible for the worldwide generation of earthquake activity. Earthquakes occur predominantly along plate boundaries and to a lesser extent within the plates. Intraplate activity indicates that lithospheric plates are not rigid or free from internal deformation.

Recurrence interval (see *return period*).

Response spectrum: The peak response of a series of simple harmonic oscillators having different natural periods when subjected mathematically to a particular earthquake ground motion. The response spectrum shows in graphical form the variations of the peak spectral acceleration, velocity and displacement of the oscillators as a function of vibration period and damping.

Return period: For ground shaking, return period denotes the average period of time — or recurrence interval — between events causing ground shaking that exceeds a particular level at a site; the reciprocal of annual probability of exceedance. A return period of 475 years means that, on the average, a particular level of ground motion will be equalled or exceeded once in 475 years.

Risk: Lives lost, persons injured, property damaged and economic activity disrupted due to a particular hazard. Risk is the product of hazard and vulnerability.

Rupture area: Total subsurface area that is supposed to be sheared by the earthquake mechanism.

Seismic microzoning: The division of a region into geographic areas having a similar relative response to a particular earthquake hazard (for example, ground shaking, surface fault rupture, etc.). Microzoning requires an integrated study of: 1) the frequency of earthquake occurrence in the region; 2) the source parameters and mechanics of faulting for historical and recent earthquakes affecting the region; 3) the filtering characteristics of the crust and mantle along the regional paths along which the seismic waves are travelling; and 4) the filtering characteristics of the near-surface column of rock and soil.

Seismic zoning: The subdivision of a large region (e.g., a city) into areas within which have uniform seismic parameters to be used as design input for structures.

Seismogenic source: Area with historical or/and potential earthquake activity with approximately the same characteristics.

Seismotectonic province: Area demarcating the location of historic or/and potential earthquake activity with similar seismic and tectonic characteristics. The tectonic processes causing earthquakes are believed to be similar in a given seismotectonic province.

Source: The source of energy release causing an earthquake. The source is characterized by one or more variables, for example, magnitude, stress drop, seismic moment. Regions can be divided into areas having spatially homogeneous source characteristics.

Strong motion: Ground motion of sufficient amplitude to be of engineering interest in the evaluation of damage resulting from earthquakes or in earthquake-resistant design of structures.

Tsunami: Large sea waves caused by submarine earthquakes travelling over long distances and thereby forming disastrous waves on shallow-water seashores.

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